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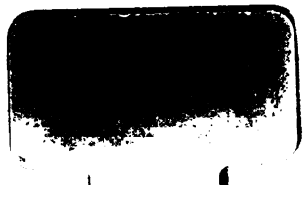

Water

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I.

Measuring Water

BY

CLEMENS HERSCHEL

HYDRAULIC ENGINEER

WITH THE RESPECTS OF

CLEMENS HERSCHEL,

ENGINEER AND SUPERINTENDENT OF THE EAST JERSEY WATER CO.

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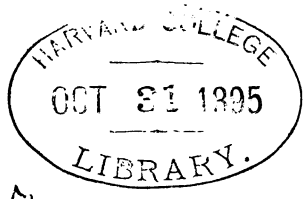


PRESS OF LIVERMORE & KNIGHT CO., PROVIDENCE, R. I.

Measuring Water

By Clemens Herschel, Hydraulic Engineer.

The subject which I have selected for this discourse
ɔe called "Measuring Water," or to particularize,
easurement of a *stream* of water; being the deter-
ion of the cubic volume of water that thus passes a
point in the adopted unit of time. For most pur-
the unit of volume, when using English measures,
ɛen agreed upon in favor of the cubic foot, and the
ıs of the earth being fortunately agreed upon their
ıres of time, have settled upon one second of time
: unit to use in measuring water. Nevertheless, the
ın United States gallons in twenty-four hours has
ıe a standard for city water supply practice in the
ɛd States, and an acre in area covered an inch, or a
deep in a month, or in a year, is used in irrigation
ce. But I would warn all engineers to be very slow
d to the number of such standards of measure for
ıg water, and to abstain from and frown down such
d standards as cubic yards per day, or tons weight of
per day, or even cubic feet per minute (instead of
d) and other incongruities found mainly in the writ-
ɔf British engineers. As exercises in the art of
netic for children, such computations may have value,
ı the work of civil engineers they become a stumb-

ling block to an advance of knowledge, and while unduly magnifying the unessentials, they indicate a deplorable lack of appreciation of the essentials of the art of the civil engineer.

Cubic measures do well enough for the contents of vessels, or as we may express it, for dealing with the science of hydrostatics. But so soon as the water to be measured is in motion, or so soon as the science of hydraulics has been entered upon, we must get clearly in our minds the idea of rates of flow, or of a procession of such cubic volumes passing a given point in a certain unit of time, as of a flow of so many cubic feet per second.

No such idea appears to have formed part of the stock in trade of the ablest engineers in ancient times, or at the beginning of the Christian era, nor probably for some 1,500 years later. Thus Frontinus, perhaps the earliest writer on practical hydraulics that we have, has barely a conception of the fact that some streams of water flow faster than others, but his measurement of any and of all streams is based solely upon the areas of their cross-sections. You can readily see how imperfect is such a conception of the volume of a flowing stream; though we must admit that to this day many a man yet struggles with the similar crudities of "the amount of water that will fill a 6-inch pipe," or of so many "square feet of water" let unto a water wheel and the like; when, as has been said, he might as well attempt to define the volume of a cylinder, or of a parallelopipedon by giving only the area of its base.

A stream of water, then, is defined by stating what it will produce in a unit of time; usually the cubic feet it will produce in one second of time. And this definition could not become current even among experts until considerable attention had been paid to measuring the velocity of running water. These measurements, again, had

their origin in the search for the numerical values of velocities of efflux through orifices and out of vessels of water; in the establishment of the equation, known to all of you, the fundamental equation of the whole modern science of hydraulics: $v = \sqrt{2gh}$

You may know that this equation was first published in 1732 by John Bernouilli of Basle, Switzerland, though his son Daniel Bernouilli was credited by his father with having furnished an independent proof of the same relation between head and velocity of efflux, at the time, and in 1738 the son published his own celebrated "Hydrodynamica." But these two founders of the modern science of hydraulics had been preceded by, and had had the benefit of the labors of many generations of earnest workers in the applied sciences. If I may be allowed to quote from myself, I give you on this point an extract from my lecture on "Frontinus and his II. Books on the Water Supply of the City of Rome, A. D., 97," published in the 1894 number of the Journal of the "Association of Civil Engineers of Cornell University:" "We who have been educated in English-speaking countries have been accustomed to consider Lord Francis Bacon (1561-1626), as the author and apostle of the experimental method of studying science. But modern research shows him to be entitled to the latter credit, only as he influenced his countrymen of Great Britain, and he himself made no experiments of any note. For a hundred years before his time lived that remarkable painter, sculptor, teacher and engineer, Leonardo da Vinci (1452-1519), the misfortune of whose fame it has been that his voluminous works, hidden away for centuries in private keeping and exposed to manifold vicissitudes, found no publisher until the last few years; and have, even to-day, not been before the public long enough to be used by modern writers, as they undoubtedly will be. He not

only preached the duty of study by means of experiment, but was himself a most prolific experimenter and a teacher. In the last named way he anticipates Lord Bacon; in the other he is the forerunner even of Galileo. His experiment on the law of falling bodies is most interesting in connection with the matter we are now considering. He used two long boards hinged together like the leaves of a book. On the inside, these boards were smeared with tar, or wax. A string latch served to suddenly close them. He then takes a small tube, filled with shot, the tube having nearly the same diameter as the shot. This tube is held vertically in and over the angle of the wooden book, itself set up vertically. The shot are then allowed to drop out, and on pulling the latch, are caught as they fall, between the leaves of the wooden book, and their relative distances, as they are falling, are impressed on the tar or wax covering of the boards.

Until quite recently Galileo has been supposed to have been the first experimenter on the laws of falling bodies, but here was this great engineer and teacher busily at work at it, 100 years previously. However, with Galileo, (1564–1642), we first touch the modern science of 'dynamics,' or of bodies in motion. Says Rühlman: 'for the proper founding of the science of dynamics, or of the science which treats of the causes and the laws of motion, were requisite talents of a degree of eminence, such as the Lord Almighty called into being with Galileo in the year 1564.' But Galileo had no proper means for measuring time, no clocks or watches. Both he and his son tried to make a clock, but did not succeed. Instead, he used a large bowl of water, having a small orifice at the bottom, and compared times by the weights of water discharged during these times, using his finger to start and stop the flow of water out of the bowl. As we shall see, it is a reasonable assumption that this makeshift of a

clock became, in the hands of Galileo's pupils, and of those of his pupil's pupil, the suggestion for an experimental demonstration of the laws of efflux in general.

Castelli (1577–1644), the pupil of Galileo, was a Benedictine monk, from that same Monte Cassino which saved Frontinus' commentary to posterity, and he first showed that the quantity of efflux, in a given time, depended by law on, or was a function of, the depth of water in a bowl, such as the one just spoken of; that is, was a function of the head. But he wrongly stated this law, making the quantity vary directly as the head. It was his pupil, Toricelli (1608–1647), the inventor of the barometer, the grandson, in a professional sense, of Galileo, who first proved, in 1644, or only two years after Galileo's death, that the velocities of efflux are as the square roots of the head. But this still furnished no numerical value for the velocity of efflux. Still another, and still other great men, had to devote their lives to this cause. Thirty more years had to pass by, till Huygens (1629–1695), the inventor of pendulum clocks, first found the numerical value of the acceleration of gravity, commonly represented by the letter g in 1673, and sixty-five more years had to elapse, until the genius of the two Bernouillis, father and son, in 1738, or 250 years after Leonardo da Vinci, finally laid the foundation of modern terminate hydraulics by writing the equation of $v = \sqrt{2gh}$. every letter and character of which may be considered the contribution of and a tribute to the skill and perseverance of one or more of the many great men I have named. v. may stand to symbolize the experiments of da Vinci and Galileo, $2g$. alone would suffice to immortalize Huygens, were he not already permanently distinguished by his invention of pendulum clocks and other works; h. may serve to re-call Castelli, and the square root sign, his pupil, Toricelli, and when next we write the

formula, let us remember that it took 250 years of work, not to speak of another and a preceding 250 years or more of speculation to put it upon the blackboard of the world. But no amount of speculation alone, or of peripatetic philosophy, would have produced it. To do that, the work of centuries of earnest men, not too proud to dip their hands into bowls of water, and to *experiment* in hydraulics, the while they were wearing mechanics' overalls, so to speak, was absolutely necessary."

Men of this stamp have followed, since 1738, in rapid succession, and were hydraulic observatories endowed with but a small portion of the wealth that has been devoted to furthering astronomical recreations, very much more such work would have been done up to the present time. Indeed it is sad to consider how much has been as yet withheld or lost to the world for the want of endowed hydraulic observatories. It was Galileo, who more than 200 years ago deplored this state of affairs, and declared that, strangely enough, he could learn more of the movements of Jupiter's satellites than he could of a stream of water on the earth which he inhabited.

But working in the best way they could, the practical part of the science of hydraulics and the art of measuring water, has been developed since 1738 by many earnest workers in this field, some of whom I will name in the order of their birth:

Michelotti, the elder,	1710 to 1777
Brindley,	1716 to 1772
Chézy,	1718 to 1789
Smeaton,	1724 to 1792
Bossut,	1730 to 1814
Du Buat,	1732 to 1787
Borda,	1733 to 1799
Venturi,	1746 to 1822
Prony,	1755 to 1839
Woltmann,	1757 to 1837

Michelotti, the younger,	1764 to 1846
Eytelwein,	1764 to 1849
D'Aubuisson,	1769 to 1841
Thomas Young,	1773 to 1829
Bidone,	1781 to 1839
Poncelot,	1788 to 1868
Lesbros,	1788 to 1867
Darcy,	1803 to 1858
Weisbach,	1806 to 1871
Francis,	1815 to 1892

and by Boileau, Bazin, Borneman and a host of others still living, as well as many, such as Pitot, Cabe, and others of the years prior to 1738. These are the men to whom we owe the present state of the art. It is true that much that they have done, has become nigh useless in the practical pursuit of measuring water; but all science, all knowledge is thus developed with the accompaniment of a great waste of energies, somewhat as the operations of nature include a waste of labor and of benign possibilities. Thus the multitude of experiments on efflux from vessels and through orifices can find but little use in practice. The intent seems to have been to so study efflux as to deduce its laws up to the point of being able to meter water from a knowledge of the size and shape of the orifice and the head acting upon it. Speaking from the standpoint of the practician, this has not been accomplished, nor is there any present outlook that it ever will be accomplished. Each shape, each minute variation of shape, each accompanying circumstance of efflux, varies the co-efficient of discharge; so that the most that can ever be affirmed is that a precise reproduction of an orifice that has been experimented on and a reproduction of the attending conditions will reproduce the experimental discharges. This is the sum total of our knowledge even in a case apparently so simple as that of water wasting over a weir. I say apparently so simple,

because as long known, the latest experiments of Bazin have clearly shown the multiplicity of forms according to which water may proceed to spill over a weir.

Returning to the case of discharge from an orifice, we have here probably the earliest method devised for measuring water. Frontinus, who wrote A. D. 97, described how water was metered to the Roman water-takers. It was lead from the aqueducts to a group of cisterns set up near the places of final consumption of the water, and into the walls of these cisterns were inserted bronze, circular, ajutages, about nine inches long, of the desired diameter stamped with their size and the name of the water works superintendent who had set them. Two specimens of these ajutages have survived the wrack and ruin of the centuries and are preserved in two of the Roman museums. Frontinus knew that these ajutages must all be set on the same elevation, that is, as we would now say, under equal heads, to cause them to discharge equal volumes, but to show you how crude were his ideas, and those of the most learned of his contemporaries on these subjects, I quote what he says about it: "In setting ajutages care must be taken to set them on a level and not place the one higher up and the other lower down. The lower one will swallow up more; the higher one will suck in less, because the current of water is drawn in by the lower one." Frontinus, 113.

Frontinus also knew that the ajutages must be set with their axes at right angles to the trend of the current, and that they would discharge more or less than the ajutage set at right angles, if set inclining with or against the current; finally, he knew that a large pipe attached to the down-stream end of the ajutage would carry more water than a pipe of the same diameter as the ajutage, attached in the same manner; and a law of ancient Rome prescribed that the diameter of the attached pipe must be the

same as that of the ajutage, for a distance of 50 feet down stream from it. But with these precautions Frontinus apparently exhausted his means of measuring water, and the resources of his time, to the end that the measurements should be consistent among themselves. His unit was the discharge of such an ajutage $\frac{5}{4}$ of a digit (about 0.907 inch English) in diameter; which he calls a quinarium, or as we would say, a "fiver." For an ajutage of double this area, the discharge becomes two quinaria, by reason of such double area; and so on, even up to the measurement, by a cross-sectional area of the stream flowing in an aqueduct, of the discharge of that aqueduct.

Of course, work like this can represent only an embryonic state of the art of measuring water. But it endured for yet 1,543 years, until Castelli, the pupil of Galileo, saw that more water was discharged out of a hole in the bottom of his water-clock bowl when the bowl had much water in it, than it did when the bowl was nigh empty, and published his ideas about it, as we have seen, in 1640.

From this time on, especially after the proof by Toricelli, only four years later, in 1644, that the discharge varied as the square roots of the head of water on the orifice, the importance of the head of water became firmly established. Frontinus had said that ajutages should all be on a level, but it is not known at what level he set them. Old orifices for regulating and limiting, not measuring water, used for irrigation purposes in the fourteenth and fifteenth centuries in Italy, had the ordinary water level even with the top of the rectangular orifice. In 1764 the legal *measure* of water used for irrigation was established in Modena, as the amount flowing out of a defined rectangular orifice under a defined head, and this is one of the earliest recorded uses of a fixed head on an orifice to define a measure of water in irrigation practice.

Long before this, however, it had become customary among the workmen that had charge of the public fountains of Rome and of Paris to measure volumes of water by the discharge through a circular orifice in a thin vertical plate; the unit in Paris, for example, being the discharge through an orifice one Paris inch in diameter. Belidor, who wrote in 1737 says (Archit. Hydr. 11, 366) that the "fountainiers" were not particular what head was acting on the orifice so long as it was a moderate one. Their subdivisions of the water inch were also entirely irrational and erroneous. The first one who attempted to determine the meaning of a water-inch in fixed measures was Marriotte, who lived 1620–1684, and who found the discharge of a Paris water-inch, when the head on the upper edge of the orifice was 1 "ligne," about 1-12 of an inch, to be about 14 "pintes" per minute, = about .47 cub. ft. per minute. The Paris inch was about 6 per cent. larger than the English inch; and with Gallic perversity the Paris "pinte" differed less than one per cent from the U. S. quart.

Belidor notes some of the many objections to this mode of expressing a definite measure of flowing water, and strove to improve upon it by substituting rectangular orifices of uniform height, set on a level, but having varying widths, for the circular orifices of varying diameter used in his time, whose centres or bottom edges were all on a level. The method is, however, necessarily beset with so many chances for error that it never can succeed for work that aims at the merest rudiments of exactitude. Again and again in the world's history has it been attempted to introduce it, in every case by uneducated men, or in crude forms of society, only to reveal its manifold imperfections and to vex and encumber the contracts and legislation of several succeeding generations before it could be got rid of. The miner's inch, gradually disap-

pearing in our Pacific States in favor of the cubic foot per second, is one of the latest examples of the statement just made.*

The reason for this is readily seen when the multitude of dimensions and forms of the measuring apparatus, each one of which has an influence on the discharge produced, are taken into consideration. Whether the orifice be cut out of a plate 1-16 inch thick or 1-32 inch thick, or through an inch board or a half-inch board; whether the bottom of the vessel be 1″ or 3″ below the bottom of the orifice, whether the orifice be filed off smoothly or left as cut, whether the holes be punched 2″ apart or 3″ apart, and a multitude of other such circumstances, all effect the resultant discharge. The one thing to do with such a crude unit of measure of flowing water is to get rid of it, and this is happily being accomplished in the course of time.**

*See a Report to the Montana Soc. of C. Engrs., by Prof. A. M. Ryon, 1894. Also Journal of the Association of Engineering Societies, January, 1895.

** So long ago as the middle of the fifteenth century there was at least one man who saw the defects of an orifice of discharge, as a unit of measure, very clearly.

In Leonardo da Vinci's Manuscript F, (Venturi, Essai sur les Ouvrages, &c., Leonardo da Vinci, 1797, p. 20), may be found the following :

CONCERNING THE WATER THAT MAY BE DRAWN FROM A CANAL.

The quantity of water that discharges from a canal through an orifice of a given size may vary on account of many reasons :

1. By reason of the height, more or less great, that the surface of the water of the canal is over the opening.

2. By reason of the more or less velocity with which the water of the canal passes along the bank in which is placed the opening.

3. By reason of the sides of the opening being more or less convergent.

4. By reason of the thickness of the frame of the orifice being greater or less.

5. By reason of the shape of the opening being circular, or square, or triangular, or lengthened out.

6. By reason of the axis of the opening being more or less inclined to the direction of the bank of the canal.

7. By reason of its being more or less inclined to the horizon.

8. By reason of the opening being placed on a convex bank or on a concave one.

9. By reason of protuberances, or depressions in the bed of the canal opposite to the opening.

10. By reason of the air intermingling, or not intermingling, with the current of water that discharges from the opening.

11. By reason of the water discharging from the opening freely into the air, or discharging through an open conduit, or through a closed pipe.

12. By reason of this conduit having a cross-section greater or less than the orifice of discharge.

13. According as this conduit is of greater or less length.

14. According as the interior of the conduit is smooth or rough, straight or curved.

When it is considered that this was written before the invention of printing, and before Columbus discovered America, it becomes a marvellous exhibit of a thorough and searching analysis made merely by force of genius, and without aid from the teachings of hydraulic science, then as yet unborn.

Starting with the Roman attempt to measure flowing water merely by the cross-sectional area of the stream, thence passing to the mediæval way of measuring it by the number of streams one inch in diameter, under some small head, which it would produce, thence reaching the point where these small streams were defined to act under a given head, so as to regulate the affecting circumstance of discharge of greatest importance, we have at last arrived at the modern method of defining flowing water in cubic measure per unit of time, or at the definition of cubic feet per second.

I will ask you now to distinguish between mere computations that indicate the discharge from orifices, through pipes, or in channels, from instruments and methods by which such streams are directly examined and measured. The last process alone we will call measuring water. It may also not be superfluous to ask you to distinguish between forms of apparatus that may be set to discharge uniformly certain given quantities, so-called modules, as likewise not included in the instruments and methods to be used for effecting a measurement of a given stream; nor to ordinary water meters, which measure volumes, but do not measure rates of flow. But I shall include in such instruments the weir, which may be reproduced in the precise form used to establish a given weir formula, so readily, that it has won a place for itself among water-measuring instruments, something that the orifices or pipes that have been named are not likely ever to accomplish.

But a weir measurement is only a reasoning by analogy from the recorded results of measurements made over a like weir into some measuring tank, so that at the foundation of weir measurements, and at the same time as the simplest of all methods of measuring water, we have the measuring tank, or, as we may call it, the grocer's pint or

quart measure. But when conducted with accuracy, measuring water by means of a measuring-tank is an art, to be learnt like any other, some features of which may now be illustrated.

Tank volumes may be measured in two ways: either directly by cubic contents, or indirectly, by first weighing the quantity contained and then computing the cubic contents from the temperature of the contained water and from its weight per cubic foot.

If the first method be followed, the tank must be built on purpose for it, extraordinarily strong and staunch, so as not to change in shape when filled with water, and by no means to leak. If of wood, the wood must be water-logged. Levels of water must be measured with a hook gauge to thousandths and to ten thousandths of a foot. The form of the measuring-tank must be a regular one, all the corners straight, sides without warp and all linear measurements must be determined with extreme accuracy. You can readily see that it is easier to use a tank or vessel of most any make and form and to weigh the contained water.

To limit the lengths of time during which the stream, whose flow it is desired to measure, discharges into the tank, the best way is to use a movable spout between the stream of water and the tank. A carefully tested stop-watch and an assistant to cause the spout to discharge the water on a given signal into the tank and again to one side of it, will determine the length of time during which the tank received the discharge to be measured within the fraction of a second. Large movable spouts of this sort, to control discharges of considerable volume, may be found described in Francis' Lowell Hydraulic Experiments, and in the description of the experiments made with the Venturi Meter, in the 1888 Vol. of the Transactions of the American Society of Civil Engineers.

Such measuring-tanks are the very simplest forms of water-measuring apparatus, so simple that they are not thought of many a time by the hydraulic engineer, whose head may be filled with the pages upon pages treating of the cases and the coefficients of discharge given in the text books, but duplicates of any one of which cases are so seldom met with in practice. Whenever a small stream of water is to be measured, one's first thought should always be the tank, the pint measure. When that is not applicable it will be time enough to turn to other methods.

One such other method, we have agreed, shall be the weir. Now a weir may be looked upon in two ways: as a hydraulic study of the discharge of water over it, and, again, strictly as a method for measuring water. If the first view be taken into consideration, the last word has by no means yet been said upon the subject, and the latest may always be the best. But if the second named object be kept in mind, we have in Francis' Lowell Hydraulic Experiments nearly all that will ever be needed upon that subject. For the weir experiments recorded in that classic of hydraulic literature embrace all the cases of weir measurement that are ordinarily met with in practice. We have but to reproduce the conditions of those experiments to have the results at once known with the same degree of accuracy that distinguished the tank measurements recorded in this book. As is well known, no expense was spared in the conduct of the Lowell experiments to ensure extreme accuracy, and as a consequence the boon of exact knowledge on the cases of weir discharge treated in the book named has been conferred, by these experiments on succeeding generations.

Another useful method of measuring water, applicable, however, when accuracy is desired, only in rectangular channels and for the cases of a uniform flow during

the hour or more required for the measurement, is presented by the use of floating tubes. This method is a very old one, having been first used by Cabeo, an Italian professor in 1646, but the method was first accurately tested, and established as a trustworthy method of measuring water, by Mr. Francis, as related in the book that has been named, in Lowell Hydraulic Experiments. This was done by measuring the same streams of water at one and the same time, both over a weir, and by means of floating tubes. It will not be in the power of man, presumably, for many years to add profitably to what is said on this method of measuring water in the book that has been referred to.

We now come to two instruments that enable us to determine the velocity at any *point* throughout the cross-section of a stream of water. I allude to the current-meter, or moulinet, or Woltmann wheel, and to Pitot's tube.

For small streams of water, for jets, or in the interior of pipes, the latter instrument alone is applicable for a close investigation of the distribution of the velocities of the water in the cross-section of the stream. In large canals and rivers the current-meter becomes not only the superior instrument, but almost the only practicable one. Many instruments have been invented for the same purpose, or were invented in the early days of hydraulic science, but are of no more practical interest now than would be an examination of the bones of extinct animals.

Woltmann, the inventor of Woltmann's wheel, was a hydraulic engineer employed by the City of Hamburgh, who lived from 1757 to 1837, and got his idea of the current-meter from an anemometer in use in his day. Since then the instrument has been constructed in a great number of ways. At first it had to be taken from the water after each time of running some definite period of

observation to get the reading. Latterly, electrical or phonetic connection is made between the meter under water, and some form of counter above water, so that observations may be made continuously. The form of wheel, also, has changed many times. Care should be taken that the wheel be as little liable to change of form as possible, and that all parts, such as bearings that produce frictional resistance, be as constant in condition as possible. All this, so that when once rated, the instrument may not be subject to a change of rate. It is not exactly correct to assume that the method of rating usually pursued, that of dragging the meter through still water at known velocities, is mathematically equivalent to letting the water, moving at an average velocity, equal to these same velocities, impinge upon the meter held still. Preliminary reasoning would so indicate, it is true, but a closer examination reveals differences, and in hydraulics reasoning alone will never indicate the weight to be given to objections or to analogies. To do this, resource must always be had to the results of careful experiments.

A valuable attribute of the current-meter is the fact that it can be used to measure the *average* velocity in a vertical, or in a horizontal, or in a whole cross-section, by slowly moving the meter over these lines or areas and exposing it to the current for equal lengths of time over equal spaces or areas. Some excellent work of thus integrating the velocity in the cross-section of a stream and other results of experiments with the current-meter may be found described in an article by F. P. Stearns, M. Am. Soc. C. E., in the Transactions of that Society for August, 1883; and the reports of the Corps of Engineers, U. S. A., contain many examples of the use of the current-meter on the rivers of the United States. See also *Engineering News* of January 10, 1895. In Europe, also, in Germany and France, much work has been done with it.

Colonel Thomas Gardner's Quarters, Mass.

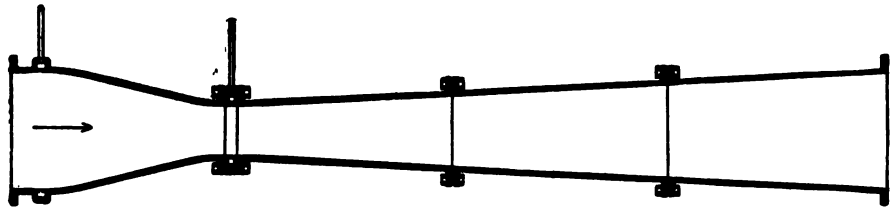
The modern use of the Pitot tube may be likened to that of a microscope in hydraulic investigations when compared with that of the current-meter. It is a very old form of current measuring apparatus, Pitot having lived from 1695 to 1771, but the instrument has received many improvements at the hands of Darcy and Bazin, and of many others. The point of a Cross Stylographic Pen, with the central wire removed, has been a favorite form of the tube which is directed against the current to be measured, and this characteristic feature will give an idea of the delicate work this instrument is capable of. Some excellent investigations of this sort are described in the Transactions of the American Society of Civil Engineers for November, 1889, page 411, in a paper on Fire Streams by John R. Freeman, M. Am. Soc. C. E.

Another method of measuring water is by means of the Venturi Meter, which has further been converted by the attachment of a suitable register into an ordinary dial meter, like the house meters commonly met with. There being hardly a limit at which the size of the stream to be metered by this meter becomes too large for it, and as the register is essentially the same for small meters and for the largest sizes, we could with the Venturi Meter register on a train of dials the daily consumption of the present or of the Greater New York, or of London, or of the two combined, as easily as that of a ½" stream. As a matter of fact, this meter has already measured the flow of water through a 9-foot tube up to over 245 cub. ft. per second, about 160,000,000 gallons per 24 hours. It has also been tested on a ¼" stream, and meters the one as readily as it does the other. Nor is it affected by or does it materially affect the pressure of water either at the intake or the delivery end, that is to say, it can be used on pipes under any pressure and destroys very little of the head or pressure for purposes of passing the water

through the meter. For instance, it need never thus destroy more than a foot of head when passing maximum quantities. A 48″ meter in use on the works of the East Jersey Water Company, for example, loses 4 inches of head to meter 25,000,000 gallons per day. And by the use of by-passes, any loss of head need obtain only during the period of measuring water.

These are some of the general characteristics of the instrument, which may now be described more in detail, the more so because its description has not yet been placed in text books generally, although Merriman's Hydraulics contains a good discussion of it.

The instrument consists of a converging, followed by a gently diverging tube; between the two is a short cylindrical piece, surrounded by a pressure chamber which is connected with the interior by piezometer holes.



A similar pressure chamber surrounds the main pipe at the inlet end, and may also be applied to the main pipe at the outlet end, if it be desired to measure the loss of head in passing the meter.

Now it is a fundamental principle in hydraulics, that the hydraulic pressure of the water against the interior of a pipe containing water in motion, is equal to the hydrostatic head, (to what the pressure would be if the water stood still,) less the head due this contained velocity.

Or if P be the pressure in the terms of the height of a water column at the inlet.

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P_1 be the pressure in the terms of the height of a water column at the throat.

v = the velocity at the inlet.

v_1 = the velocity at the throat.

P_s = the static pressure: then

$$P = P_s - \frac{v^2}{2g} \text{ and } P_1 = P_s - \frac{v_1^2}{2g}$$

Ordinarily the throat is made $\frac{1}{3}$ the diameter of the main pipe, or its area = $\frac{1}{9}$ of the main pipe area, and, therefore,

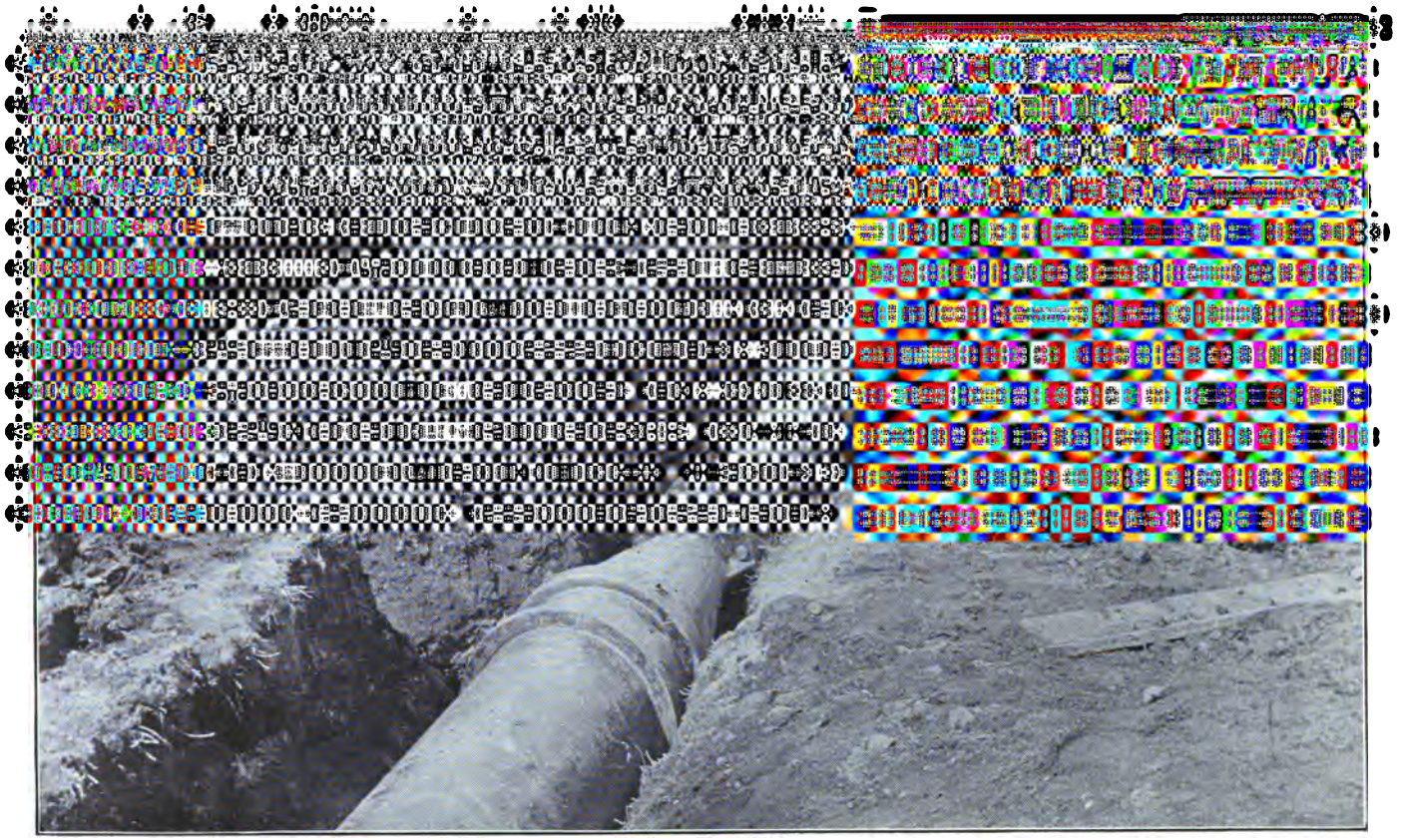
$$v_1 = 9v \text{ and } P - P_1 = \frac{v_1^2}{2g} - \frac{v^2}{2g} = \frac{80\ v_1^2}{81\ 2g}$$

But $P - P_1 = H_v$

$$\therefore v_1 = \sqrt{\frac{81}{80}}\sqrt{2g\ H_v} = 1.0062\ \sqrt{2g\ H_v}$$

Experiments show that in fact for three different meters tested, of 1 ft., 4 ft. and 9 ft. diameter of main pipe, and within the limits of velocity ordinarily met with, the coefficient to be used with this formula varies with the velocity through the three meters only from .972 to .997, which is important as fixing the discharge of any such meter without making experiments with it. After such a meter has been rated its discharge is exceedingly uniform and can be relied upon as correct within a small fraction of one per cent. for any single reading.

As the indications necessary for the measurement of the water passing through a Venturi Meter are merely the pressures in two little pipes, these same two pressure pipes may be used to operate several mechanisms without interfering with each other, which would not be true, if, for instance, the pressure pipes conveyed a *stream* of water,



20″ Venturi Meter Tube in Pipe Line Trench, Lowell, Mass.

instead of only static pressures. Thus, a diagram can be drawn by them that will indicate the *rate* of flow through the meter for any convenient length of time. This makes the meter a so-called waste-water meter, used to find and to locate leaky house fixtures in cities. But the same pressure pipes can be used to operate the ordinary form of register, thus metering the water as in the common forms of dial meters. And they can also show their contained pressures directly in glass tubes, or on Bourdon, or mercury pressure gauges, affording the means of testing the several instruments by computed results.

I have come to the point of being ready to set the tubes of these meters at selected locations throughout the distribution system of cities, so as to be able to meter the consumption of any *one* or more of its several districts, at any desired time. The loss of head occasioned is so small, no more than is caused by a square turn, or branch, and not so much as is caused by a check-valve, that no by-passes need be set. Whenever desired, a dial register, or a waste-water indicator, can be set up at any convenient place, 1,000 feet, if need be, from the tube, and connected with it permanently or temporarily. Of course every system of water works should have a Venturi Meter on its main pipe or conduit, just as every gas works has a master meter to measure its total output of gas.

If set in the penstocks leading to turbines, or in the tail races of mills as ordinarily situated, one or more by-passes can be provided in very particular cases, if desired, which can remain open when the meter is not in use, to avoid the few inches loss of head occasioned by the meter when it is in action, unless, indeed, the situation is such that a few inches loss of head can be compensated for or such that they are of no consequence.

When set in an open channel, the case becomes somewhat peculiar. The pressure at the throat is then a nega-

tive one, or is measured by the amount of suction, or of "vacuum" it will produce. But the *difference* of pressure between the same two pressure pipes, governs the indications of the meter, as before, and the total loss of head is much less than if a weir had been used. In this form, and built of wood, the Venturi Meter is destined, in my belief, to do important work in irrigation practice. Also in the measurement of sewage, in which case the meter tube can be built of brick, and with the invert grade line undisturbed, by placing the throat area excentrically to the area of the main sewer.

Making full use of "new fangled notions" is peculiarly the province of the rising generation; and I look confidently to the hydraulic engineers among my hearers to profit by the fact that a meter which can be set in a pipe of any diameter, and of the simple construction that has been shown you, can now be put to use in their practice.

30″ Venturi Tube, Bell and Spigot Ends

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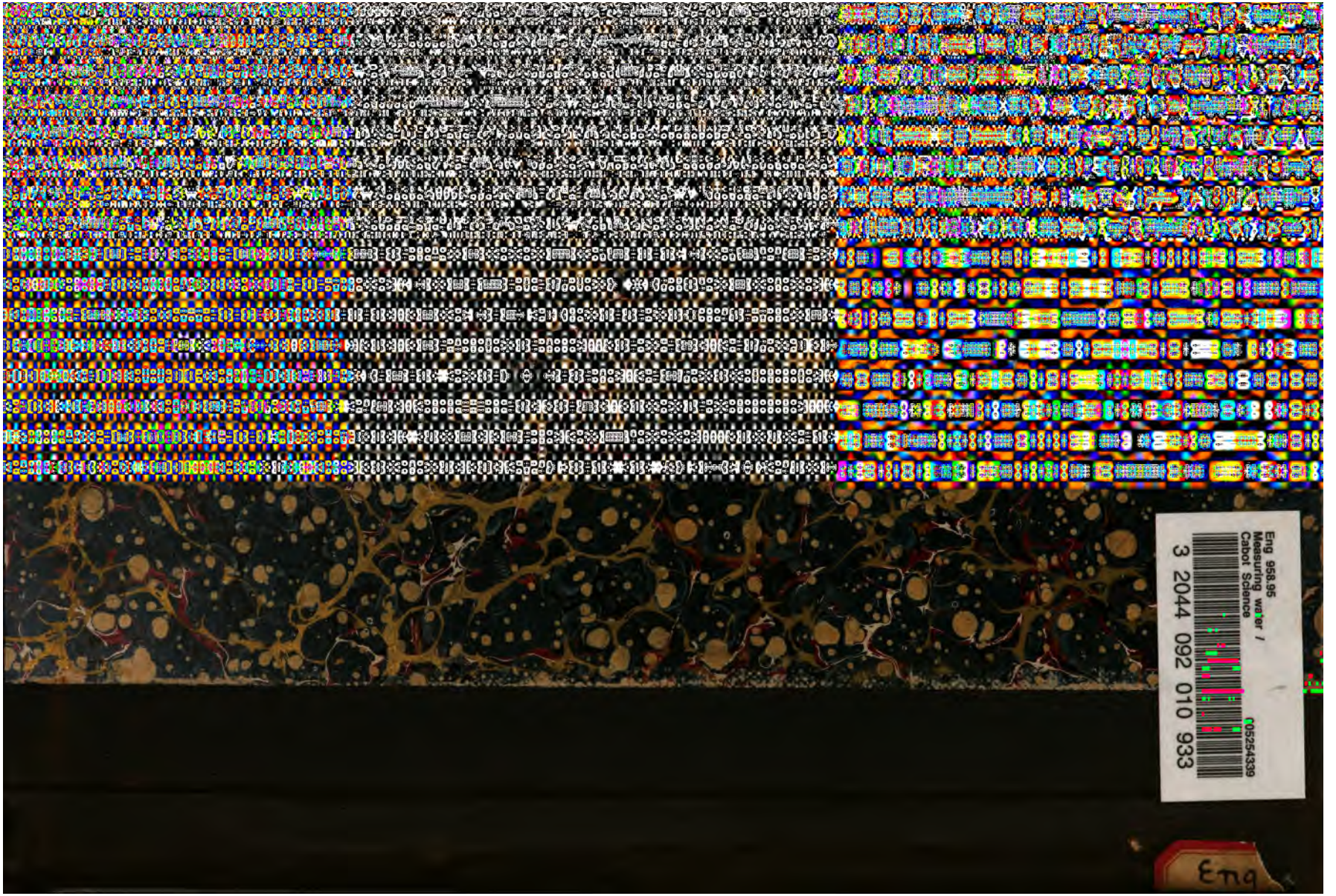
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